AL.2.1991-326

DEVELOPMENT OF AN EFFECTIVE QUALITY ASSURANCE PROGRAM FOR EXPOSED RESIDENTIAL CONCRETE FLATWORK

CANADIANA

JUN - 4 1991

Alberta
MUNICIPAL AFFAIRS
Innovative Housing Grants Program

DEVELOPMENT OF AN EFFECTIVE QUALITY ASSURANCE PROGRAM FOR EXPOSED RESIDENTIAL CONCRETE FLATWORK

September 1990

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The views and conclusions expressed and the recommendations made in this report are entirely those of the author and should not be construed as expressing the opinions of Alberta Municipal Affairs.

With funding provided by
Alberta Municipal Affairs

ISBN: 0-88654-297-9

FOREWORD

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ACKNOWLEDGEMENTS

The assistance and support of the Alberta Ready Mixed Concrete Association and the sponsoring concrete supply companies are gratefully acknowledged. Additionally, it is recognized that the successful execution of the field testing program, which at times required very delicate handling, was largely due to the skillful efforts of Mr. Chris Huizer, the field technician.

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EXECUTIVE SUMMARY

Flatwork, the category of concrete which includes driveways, garage floors and aprons, sidewalks and patios, is commonly exposed to freezing and thawing conditions in a moist environment often in the presence of deicing chemicals. Flatwork is discussed in the specifications of CAN3-A23.1, Concrete Materials and Methods of Construction, and CAN3-A438-M84, Concrete Construction for Housing and Small Buildings, and in Part 9 of the Alberta Building Code. However, in the residential application, the requirements of those documents are seldom enforced because residential flatwork is seldom inspected by jurisdictional or owner-appointed authorities. The primary objectives of this project were to identify present trade practices which can lead to poor performance or failure of residential flatwork, and to develop remedial recommendations and strategies.

A preliminary study undertaken during the summer of 1988 in Calgary with the support of the Alberta Ready-Mixed Concrete Association (ARMCA), demonstrated clearly that a need exists for either an "authority" presence and/or for other effective, protective considerations for this type of construction, particularly at the working level where mix modifications and perceived substandard finishing practices were found to occur. It was found that the ready-mixed concrete producers were supplying concrete of a quality far above minimum permissible standards. As part of this study, which was initiated in 1989, a condition survey was performed at all of the sites investigated in the 1988 preliminary study. Although not of alarming proportions, all observed flatwork distress, except for one case, was related to factors other than substandard materials.

In support of the study objectives, a field testing program, with the support of ARMCA was undertaken to evaluate on a random basis the quality of supplied fresh concrete and its handling and placement at the site. The parameters monitored included fresh concrete air content and slump and, in some instances compressive strength. Additionally, observations of substandard handling, placing and finishing practises were made and notes on site preparation were taken. A total of 123 sites were visited during concrete placing and finishing activities.

Through analysis of the test data and observations and examination of related technical issues within the context of current practise in concrete technology, the following findings were derived:

1. At least ten percent of the concrete delivered contained a total air content at, or near, the lower permissible limit. Only one concrete delivery with substantially lower air content than permitted was detected.
2. Over thirty percent of the concrete had a slump higher than permitted; however, in no case was there evidence of excess bleeding, laitance, segregation or mixture instability.
3. The compressive strengths of mixtures thought to possess undesirable characteristics initially, such as high slump or concretes where water had been added, were within specifications with two exceptions.
4. Inappropriate addition of water to the mixture in the truck occurred at approximately seven percent of the sites which resulted in slump values higher than specified, but low strength was observed in only one case.
5. Water was added to the surface of the flatwork prior to finishing at approximately six percent of the sites.
6. Concrete was placed on wet and/or soft subgrades at twenty percent of the sites.
7. In general, there was inadequate compaction effort with premature final finishing of the fresh concrete. However, there was evidence of widespread use of curing compounds on the finished flatwork.

The field testing program addressed a number of key components in the overall objective of the development of an effective quality assurance strategy for this category of concrete. It has been determined that there exists considerable potential for failure under severe conditions as a result of a number of workmanship-related issues. As a result, key issues were identified and discussed in the context of a longer term solution. These are consumer awareness, trade certification and future site inspection. These issues were also identified as the key components of a quality assurance program. Improved consumer awareness would help create

the demand for quality workmanship by certified tradesmen, trade certification would impart the necessary knowledge and skills to practitioners, and site inspections would provide a means of monitoring field work and enforcing trade and standards requirements.

1.0 INTRODUCTION

The primary objectives of this project were to identify present trade practices which can lead to poor performance or failure of residential flatwork, and to develop remedial recommendations and strategies. This category of concrete, which includes driveways, garage floors and aprons, sidewalks and patios, is commonly exposed to freezing and thawing conditions in a moist environment often in the presence of deicing chemicals. Although treatment of this classification of concrete is covered in the relevant specifications of the Canadian Standards Association and the Alberta Building Code, these measures are seldom enforced due to the absence of a visible "authority".

This project took place in Calgary, Alberta. The City of Calgary is the authority to the property line and for materials and practices in the structure and attachments thereto. However, the quality of the installation of flatwork on private property, with the exception of issues pertaining to sulphate soils, is not the City's responsibility. In the absence of policy and enforcement efforts, responsibility for the proper installation is not clear, and lies somewhere amongst the concrete supplier, owner, builder and/or concrete finisher. The absence of a clear line of responsibility in an otherwise heavily regulated industry severely affects the ability to determine liability, which results in an invitation to substandard material quality and workmanship. This challenges the very spirit of the legislation while risking the erosion of the image of concrete as the "traditional" residential paving material and the solid reputation of the cement and concrete industry, a cornerstone industrial resource in Alberta.

A preliminary study, undertaken in Calgary during the summer of 1988, demonstrated clearly that a need existed for either an "authority" presence or other effective protective considerations for this class of construction, particularly at the working level where mix modifications and perceived substandard finishing practices were found to occur. As part of this study a condition survey was performed at some of the sites investigated in 1988 where questionable installation practices occurred. The results of the survey are presented in Section 2.2 of this report.

In support of the primary study objectives, a field testing program was undertaken in 1989 to evaluate, on a random basis, the quality of supplied fresh concrete and its handling and placement at the site. The parameters monitored included all pertinent delivery slip information - time of test, mix temperature, entrained air content, slump and compressive strength. In addition, observed substandard handling, placing and finishing practices were noted as were the prevailing weather conditions and extent of site preparation.

An overview of test results and observations is presented with a discussion on related standards, specifications and technical issues. Finally, conclusions are summarized and a series of recommendations for a remedial action plan and implementation strategy to prevent improper trade practice, are presented.

2.0 PRELIMINARY INVESTIGATION

2.1 Pilot Project

During the summer of 1988, a pilot fresh concrete field testing program was undertaken in conjunction with the Alberta Ready-Mixed Concrete Association (ARMCA) and seven of its ready-mixed concrete supply members. The study was prompted by the occurrence of a number of frost-related failures on recent installations of flatwork constructed with concrete materials with an otherwise good service history.

2.1.1 Procedures and Observations

The program involved visits to a total of 99 sites at which concrete was being placed. Both concrete quality, assessed by testing for air content and slump, and finishing procedures were observed.

2.1.2 General Observations

The survey showed low entrained air content and high concrete slump at only four sites. In contrast, poor handling, placing and finishing practices were observed at 14 sites. These included the addition of water to the mixture both before and during placing, and the spraying of water on the flatwork before and during finishing.

Common practice at virtually all sites visited included absence of effective consolidation, finishing too soon after placing (apparently without regard for settlement and bleeding) and absence of the use of curing compounds or protection of finished work. Further, it was common that concrete was cast on subgrades containing uncompacted backfill left soft following a period of rain.

2.2 Condition Survey

2.2.1 Procedures And Observations

The study began in the spring of 1989 with a condition survey of all of the installations of exposed residential concrete flatwork sites visited in the 1988 pilot project. All surfaces were examined for damage.

2.2.2 Discussion Of Results

Generally, load-related random cracking was the most predominant failure, occurring at seven of the sites surveyed. Since the observation of soft subgrades was not noted relative to any of those sites, no correlation examination was made. This occurrence is commonly due to differential settlement beneath the flatwork or between the flatwork and the building, or both. The importance of structural considerations notwithstanding, external loads may, or may not, have been a factor. Further, excessive live loads common to construction and commercial traffic can be involved early in the life of a pavement, which complicates the analysis.

Flatwork distress related to freeze-thaw cycling was the second most frequent failure. This occurred as popouts and spalling, due to coarse aggregate disruption, and various degrees of scaling at the finished surface ranging from very slight to severe. A direct cause was identifiable at only one of the six sites with this type of distress. At this site the concrete contained an air content of only 2.2 percent compared to the specified minimum of 4 percent. This resulted in considerable scaling in the proximity of vehicle parking areas.

At three sites, very fine crack patterns, principally associated with drying shrinkage at the top of the flatwork, became visible on wetting of the concrete surface. These visible cracks can provide access lanes for water during the freezing season and become a greater durability concern the more severe the exposure and the larger the width of the crack.

The degree of cracking depends mainly on the water content of the mix at the time of setting, the tensile strength of the concrete at the time of drying and the rate of drying of the surface. Normally, if a curing compound has been used and the concrete has been properly protected during the early stages of curing, drying shrinkage cracking is of little concern with respect to durability. There were no signs of freeze-thaw related distress at any of the sites exhibiting this mode of cracking.

3.0 FIELD TESTING PROGRAM

3.1 Overview

A field testing program was developed and implemented in 1989 with support from ARMCA and six of its member ready-mixed concrete suppliers. The program was modified using experience gained during the pilot project of 1988. The program involved visitations by a field technician to sites at which exposed residential concrete was being poured. Here, a series of site observations and fresh concrete tests were performed.

The information that was gathered was issued to the supporting companies on an ongoing basis so as to provide them with the opportunity to take corrective action as deemed necessary. This aspect of the program is discussed further in the following chapter.

A vehicle provided by the supporting concrete suppliers was used by the field technician to visit sites and to transport test equipment. The vehicle was equipped with a mobile telephone which proved to be an efficient and effective medium to track the producers.

Once the condition survey of the 1988 pilot program sites was complete (May, 1989), the field testing program commenced and continued until the end of August, 1989. A total of 123 sites were visited during this period.

The program was resurrected for the purpose of a cold weather study during the month of November. Only seven sites were visited during the cold weather study due to the low level of industry activity as a result of low ambient temperature, snowfall and/or snow cover. This amount of data is too small to permit meaningful discussion. Generally, the economics of this class of concreting under such conditions precludes the adoption of the special measures necessary for subgrade preparation and concrete protection.

3.2 Site Selection

Commencing in the early hours of each day, the field technician placed telephone calls from the mobile unit of the dispatch office of each of the supporting suppliers and obtained a list of addresses for which orders for concrete for exposed residential installation had been placed. Given consideration for proximity with respect to the current location of the mobile unit, expected time of concrete delivery and concentration of potential sites with respect to city quadrant, a site visit strategy was formulated.

It was soon learned that an open approach to scheduling improved the frequency of site visit opportunities. The constraints placed on visitation activities by construction priorities and the approximate nature of delivery time made rigid scheduling less productive. The mobile telephone permitted ongoing schedule revision through convenient communication with dispatchers.

3.3 Site Procedures

3.3.1 Formalities

Initially, the field technician introduced himself to the site personnel and explained, as necessary, the purpose of his presence. This formality decreased in frequency with increasing and rapid industry awareness of the program.

Once fresh concrete testing was completed, the truck driver was informed of the results verbally. It was left to the driver's discretion to judge the appropriateness of remedial action at the batch plant. At no time did the technician provide technical advice to either the truck driver or the concrete finishers.

3.3.2 Data Acquisition

Data gathered from each site was recorded on a Test Report Worksheet. Each site was assigned a site number at the time of the visit.

The contents of the worksheet included the site address, the identity of both the supplier and the finisher, a description of the pour, the delivery slip information, the results of the fresh concrete tests, the ambient weather conditions and comments and observations relevant to pertinent site conditions and notable undesirable finishing techniques. A portion of the worksheet was provided for a sketch of the placement area to be used, if necessary, to support the comments made.

Additionally, a complete photographic record was maintained of each site visited to be used for future reference, as required.

3.3.3 Fresh Concrete Testing

The fresh concrete tests were performed in accordance with the specifications of the Canadian Standards Association (CSA). The concrete was tested for slump and air content as specified in CAN3-A23.2, Methods of Test for Concrete, parts 5C and 4C, respectively. The time of the tests and the ambient temperatures were also noted.

The test concrete was sampled after a portion of the load in the truck had been discharged. This point of discharge was recorded on the Test Report Worksheet.

At some sites, where it was deemed by the technician to be necessary, duplicate 150 dia x 300 mm cylinders were cast to test for the compressive strength of the concrete. This was done, principally, at sites where it was observed that water had been added to the mix in the truck. The cylinders were stored at the site overnight in curing boxes designed for the purpose. Ice was used in the boxes during hot weather to maintain the curing temperature below 25 degrees Celcius. The initial curing temperature was monitored using a max/min thermometer which was mounted in each curing box.

The concrete cylinders were gathered the following day, transported to the laboratory, removed from the moulds and stored in a moist curing room until the age of 28 days. At this age the cylinders were capped with a sulphur-based compound and tested in compression in a hydraulic testing machine in accordance with the specification of CAN3-A23.2, part 9C. After testing for compressive strength, the specimens were stored for future reference, as necessary. Future testing could include the microscopic analysis of the air void system.

4.0 TREATMENT OF RESULTS

4.1 Ongoing Reporting

All of the information acquired at the sites and recorded on each Test Report Worksheet was entered on a computer spreadsheet by site number. This file was updated on an ongoing basis.

Periodically, each of the participating companies were sent a collection of copies of each of their respective Test Report Worksheets. Additionally, on a monthly basis, a copy of the current air content frequency distribution diagram was sent to each company. The diagram included the company's calculated average air content of as-delivered concrete. This information provided each company with the opportunity to take any necessary corrective action.

Information circulation procedures were augmented with presentations at the regular meetings of the ARMCA Marketing Committee.

4.2 Calculations And Analysis

4.2.1 Materials

All data was recorded to be source-company specific so as to permit examination of all materials-related issues on a more common basis, at least inasfar as the origin of mix ingredients was concerned. In all cases, analysis was based on comparison with specified values (values as shown on the delivery tickets) since these values govern the design of the concrete mixtures.

Properties of the as-delivered concrete, treated as described above, are presented in bar graph form as Figure 1, Figure 2 and Figure 3 (pages 30 to 32) for air content, slump and compressive strength, respectively.

4.2.2 Workmanship

For purposes of data treatment, workmanship includes the handling, placement and finishing of the concrete as delivered to the site. Since modification of the concrete mixture through the addition of water to the truck is normally prompted by the finishers, this action is considered a handling, hence workmanship, issue. Further, since site preparation is normally the responsibility of the contractor, the problems associated with wet and soft subgrades and the use of reinforcement are included under this subsection.

The frequency of occurrence of activities perceived not to be consistent with good practice were calculated. Specifically, this included the addition of water to the mix in the truck prior to finishing, the addition of water to the concrete during placement and finishing and the placement of concrete on wet and/or soft subgrades. This occurred at 15 percent, 6 percent and 20 percent of the sites visited, respectively. For the cases involving modification of the mixture through the addition of water to the truck, the slump and compressive strength were compared with specified values and are presented as Figure 4 and Figure 5, respectively (pages 33 and 34).

5.0 DISCUSSION

If the design requirements of the flatwork, base and subgrade are met and proper placing procedures are followed, satisfactory performance should be ensured if the concrete complies with the specifications. The parameters specified in CAN3-A23.1 provide a range within which concrete is deemed acceptable for use in a given class of exposure; this is "A" in the present case. The class includes a spectrum of examples ranging from bridge decks to garage and parking floors. Clearly, in extreme cases, there is a vast difference in severity of exposure between these examples in the public domain, where quantities of deicing chemicals are commonly used, and the private residential applications.

The severity of the service environment is increased by the presence of moisture, the frequency of freeze-thaw cycles, the rate of freezing and the minimum temperature reached during the freezing cycle. Since deicing chemicals depress the freezing temperature of the solution at the pavement surface, prolonging the presence of moisture, their use contributes to the severity of the exposure. Further, salts contained in the deicing chemicals affect the pH of the pore solutions in the concrete and promote corrosion of the reinforcement. The severity of exposure at the vehicle parking area on residential driveways and garage floors can be due to the collection of solutions carried in by the vehicle from salted public roads.

It must be recognized that a full spectrum of severity of exposure among installations exists depending on drainage (subsurface, surface slope, etc.) and solar radiation (shade, facing direction, reflectivity of garage door, etc.) as well as the snow and ice control activities of the homeowner. These site-to-site differences suggest that even if concrete of questionable quality is used and/or if poor placing and finishing techniques are used, failure may not necessarily be imminent. This, naturally, would be dictated by exposure severity. It is, however, indicative of the potential reduction in the useful life of the installation depending on the freeze-thaw exposure factors, as discussed.

5.1 Specifications

The primary document governing this, and all classes of concrete and concreting is the CSA National Standard Of Canada, CAN3-A23, and in the present context, A23.1, sections 14 and 17 through 22, inclusive. Reference made herein is to section and subsection numbers of this standard, only.

Additionally, minimum Alberta standards are set in the Alberta Building Code (1985), Part 9, which specifies that all concrete of this category shall be designed, mixed, placed, cured and tested in accordance with CSA-CAN3-A438-M84. This referenced standard augments the more general standard (CSA-CAN3-A23) to accommodate the flatwork concrete category.

Table 1 of CAN3-A438 specifies 100 mm as the maximum slump, 25 MPa as the minimum 28 day compressive strength and 5-8% as the acceptable range for entrained air for exterior concrete flatwork. When comparisons are drawn using test results in this report, the mix design parameters, as entered on the delivery slips, are used as the specified values. The associated tolerance limits are applied to the reported maximum, or minimum, values.

5.2 Materials

The quality of the delivered concrete is important in terms of durability and, hence, the longevity of an installation in the freezing and thawing environment. It is necessary to acknowledge that in all of the current cases the concrete constituent materials have a long successful service history in Calgary in applications far more severe than in residential flatwork. These materials are commonly used in concrete curb and gutter as well as sidewalk applications of municipal works where considerable quantities of salt are used for ice and snow control.

5.2.1 Air Content

The results of the fresh concrete air content testing, as shown in Figure 1, demonstrate that in all of the cases, but for one, the test results are within one percent of the lower design limit. Presently, there is no practical procedure to permit the physical evaluation of the entire mass of the concrete delivered except through multiple sampling. Without formal authority to interfere with the activities of the contractor, a relatively short visit time at the site results. Only an estimated evaluation of the load based on a single test was possible.

By virtue of section 18.3.5 of CAN3-A23.1, which defines acceptable load uniformity, the results of three tests for air content may differ by no more than 0.7 percent. In addition, the test procedure, a universally accepted method, permits the determination of air content in the sample to the nearest 0.2 percent, only. This level of significance is difficult to attain under field conditions. Repeatability is similarly affected. The single test result must be viewed in this context.

It is known that the spacing factor of the air-void system in the concrete is the prime parameter in terms of concrete durability and that, given an acceptable value, a concrete with a relatively low air content can be durable even when subjected to severe freeze-thaw cycling. The determination of this and other air-void parameters requires a microscopic examination of a polished internal section of the concrete and was beyond the scope of this project.

Based on single test per load results, at least ten percent of the concrete delivered contained an air content at, or near, the lower permissible limit as indicated on the delivery tickets. Again, there was only one concrete delivery of poor quality on the basis of air content.

5.2.2 Slump

The slump test is used for the mix design process in the laboratory and in a mix assessment role at the site, partly as a measure of the workability of the concrete and partly to provide a reflection of some of its properties. A surficial view of the pertinent parameters is needed in order to focus on the significance of the test results and subsequent issues.

Workability is a general term supposedly defining, at least in the traditional sense, the relative ease with which a concrete can be deformed during mixing, transport and placement. A number of the fundamental properties of fresh concrete including its shear and tensile strength and interparticle friction and others are factors influencing workability. These intrinsic properties cannot be measured at a construction site.

Hence, consideration is given to a number of practical characteristics of concrete of fundamental relevance: compatibility, the ease with which entrapped air is dislodged and the concrete reduced to minimum volume; mobility, the ease with which the concrete can be moulded or placed in constrained space; and stability, the ability of the material to remain a stable homogeneous mass without segregation of its constituents during handling and placement. Each of these characteristics depend on a combination of at least two of the several intrinsic properties of fresh concrete and are measurable using established laboratory procedures.

Conversely, slump does not represent the intrinsic nature of fresh concrete properties, directly. However, the slump value and the shape of the concrete cone can reveal useful information. True slump is an indirect and qualitative assessment of concrete shear resistance and since a flow component is present, due to gravitational effects, mobility is involved. However, since so little input energy is present, there is not much of a basis on which to estimate mobility. In the presence of shear slump, both segregation tendencies and stability of the mixture are suspect.

An additional use of the slump test and slump value at the site might be an indication of whether a mixture is at the design water content at the time of delivery or, as permitted in section 18.4.3 of CAN3-A23.1, where there is some provision for adjustment. In the latter case, it is noteworthy that by virtue of a provision in the standard for the addition of water up to 12 litres per cubic meter of concrete, it may be justified to expect that the mixture, as designed, should provide considerable latitude for the adjustment of critical constituents while in the plastic state. It is significant that hardened concrete shrinks with time upon drying proportional to the water content at the time of placement.

Other factors, originating at the plant, may well be influencing the result. For example, water reducing admixtures and air entrainment can affect slump markedly, proportional to the amount present. Changes to the proportion of any of the mixture constituents at the plant, or at the site, will affect the slump value. What is of prime importance is that the mixture is designed to be stable with the existing slump characteristics at the time of placement and for this condition, the mixture may be required to be somewhat forgiving. Whether there is justification to expect serious potential consequence depends on the sensitivity of the mixture, as designed, to changes in the relative proportions of ingredients and how this concrete is handled at the site.

Additionally, and perhaps more importantly in regard to durability, is the effect of excess water content on concrete settlement, bleeding characteristics and segregation. More detailed discussion of these topics in relation to concrete durability is included in subsequent workmanship-related sections.

Delivery slips, in all cases, indicated a design slump value of either 70 mm, 75 mm or 80 mm. From the data presented in Figure 2 and with regard for maximum permitted design slump and tolerance limits found in section 14.7 of the standard, slightly over 30 percent of the concrete that was tested possessed a slump that was higher than permitted. Regarding the arguments developed with respect to strength, settlement and bleeding and segregation in subsequent sections of this report, there is concern particularly with the handling, placement and finishing of concrete with this order of slump.

Although there were slump test values that were very high at some of the test sites, on no occasion was shear of the concrete cone ever in evidence. Further, whether by observation of the surfaces of the installations or of the test concrete during the slump test, no evidence of excess bleeding, segregation, laitance or mixture instability was noted.

5.2.3 Compressive Strength

The freeze-thaw durability of a concrete depends on far more than compressive strength since the pressures exerted by freezing water greatly exceed the strength of any concrete. Providing an acceptable air-void system is present in the properly designed and hardened concrete, and permeability has not been adversely affected for reasons associated with mixture modifications, handling or the prevailing curing regime, a concrete made with materials with a good service record can be expected to be durable.

A high slump value, significantly greater than that specified, might suggest initially that the mixture has a higher water content than provided for in the mix design. This could have a negative effect on the strength gain potential of the concrete; however, if an adequate margin of safety exists in the use of cement, there would be no net negative effect on concrete acceptability on the basis of strength. Further, and as is commonly the case for the sake of simplifying operations, the ready-mixed concrete supplier may utilize a commercial concrete mixture which is designed for much more severe service, such as in sidewalk and curb and gutter installations. The added benefit from this approach, at least in the City of Calgary, is that the quality of the product is under the constant scrutiny of a highly qualified municipal authority.

The compressive strength results, as presented in Figure 3, do not reflect the random nature of the air and slump data. They represent only the concrete that was judged by the field technician to warrant further investigation based on whether water was added to the truck at the site or the concrete possessed a very high slump. In this context, the results represent only one end of the spectrum, the one that should include the most questionable cases.

Compressive strengths specified on delivery slips were typically 25 MPa or 27.5 MPa. The strength results from all sources but two comply with specified values within the tolerances provided in section 17 of the standard.

5.3 Workmanship

5.3.1 General

A meaningful discussion of the issues related to workmanship, specifically the quality of the skill with which the concrete is placed, finished and cured, requires some background understanding on the nature of the material in the fresh, or plastic, state and during the early stages of strength development. In full, this would be a very ambitious undertaking and beyond the scope of this project. Therefore, only an overview of the topics which may be of concern in the present case will be discussed.

Between the time the concrete is deposited and screeded to its smooth and level position, the mixture is an unstable suspension of cement and aggregate particles, microscopic entrained air bubbles and macroscopic pockets of air that are entrapped beneath aggregate particles and reinforcing steel. Being denser than water, the solid particles settle slowly downwards, reducing the interparticle distance. In order to eliminate the large pockets of air which detract from the structural integrity of the flatwork as well as its durability if they become inundated with water, the placing procedure should involve some form of consolidation effort as described in section 19.4.1. This could take the form of simple shovel tamping.

Generally, from site observations, concrete compaction was not practiced. Since concrete with a high slump (>80mm) was used in nearly all cases, it is suspected that the assumption was made that consolidation/compaction was simply not necessary.

Associated with particle settlement is a rise of water and its exudation at the surface, known as bleeding, which is a normal process in all mixtures. Final finishing must be delayed as detailed in section 22.4.1 until all bleed water has disappeared and the concrete has stiffened sufficiently to prevent the working of excess mortar to the surface.

Excessive bleeding can carry fines to the surface through the channels developed and result in a scum of sand, cement and water, called laitance. This can lead to a weak and dusty surface and increased permeability of the hardened concrete, hence reduce potential durability. Further, water gets trapped on the underside of coarse aggregate which can lead to popouts during freezing. Unsound aggregate particles can lead to popouts as well.

Excessive bleeding of an otherwise proven concrete mixture is an indication that its water content is beyond the design tolerance limit. Further, it is beyond the latitude that might be expected of a proven mixture and will potentially lead to durability problems in the future. In the present case, as was discussed in the section on strength, the mixtures have a long and successful service history and, in that sense are proven. During no site visit was this condition observed.

Complicating factors, frequent in Calgary, are a relatively dry atmosphere, winds and substantial direct sunlight whereby the bleed water evaporates quickly, often as fast as it appears at the surface. This may make it virtually impossible for some finishers to judge when the concrete is ready for finishing on the basis of this criterion alone. This leaves just a qualitative assessment of stiffness of the concrete as the only provision for appraisal of readiness. This is not to suggest that this is necessarily inadequate, especially in the case of the suitably experienced and conscientious finisher.

Bleeding is slower and less evident in richer mixtures and in mixtures with a lower water content due to more cohesion. These types of mixtures will possess a greater latitude of tolerance for change in water content than lean mixtures with a wet consistency. Most of the tested concrete was found to have a slump which exceeded that specified and still no evidence of excess bleeding, shear or segregation was observed. The concretes common to this category must have a broad latitude, indeed. However, settlement and bleeding occur slowly with these concretes, and are made even less obvious under the commonly dry ambient conditions as discussed above.

During the site visits, it was observed that, commonly, the final finishing process was started quite soon after screeding and bull floating. The danger with this practice is that the surface capillaries are being closed, sealing the surface while the mass is still bleeding, and thereby trapping the bleed water just below the surface. Even if this entrapped water eventually evaporates, it will leave a cavity available to water in the hardened concrete subject to potential scaling during freezing.

The potential risk of durability problems associated with finishing slow-bleeding flatwork prematurely, suggests that the waiting period should be extended from what is common practice. Section 22.4 of the standard, dealing with final finishing, provides a guideline for this delay and suggests a range of one to four hours. Also, an effort to compact the mass during deposition may accelerate the settling process.

It is noteworthy that the use of curing compounds during the 1989 program was the norm, rather than the exception. Concrete at early ages requires moisture for strength development. As described in section 21.1 of the standard, the use of curing compounds is an acceptable method of keeping the concrete continuously moist as required for both initial and final curing.

5.3.2 Water Added To The Mix In The Truck

Since water content is normally considered a critical mixture constituent, the addition of water to the truck was perceived, at least initially, to be potentially injurious to the concrete. This occurred at 15 percent of the sites and, as seen in Figure 4, led to a slump value that was higher than that specified in approximately 50 percent of these cases. The results suggest that, for the mixtures with slump still above the specified value, but below the recommended maximum, the as-delivered concrete was probably too stiff for satisfactory placement. Therefore, there is cause for discussion on the basis of this issue only at approximately 7 percent of the sites visited.

On the basis of strength, as shown in Figure 5, it would appear there existed sufficient latitude in the affected mixtures to cope with additional water. Issues relating to strength were discussed previously. The one case of very high slump and markedly reduced strength resulting from the addition of water to the mixture in the truck may provide reason for concern at least inasfar as time of finishing is concerned for the reasons noted above.

5.3.3 Water Added To The Mix During Finishing

Water was added to the mix prior to finishing at less than 6 percent of the sites. This practice usually occurs when the surface of the mass shows signs of drying and as an aid to finishing. These measures are deemed inappropriate as covered in section 22.4 of the standard.

5.3.4 Placement On Wet And/or Soft Subgrades

Due to a very wet construction season, placement was noted to have occurred on wet and/or soft subgrades at 20 percent of the sites visited. Normally, a moist foundation for fresh concrete is desirable for the benefit of hydration of the cement. However, wet conditions can lead to problems related to settlement, consolidation and reduced bearing capacity of the underlying materials. In the absence of soil test data in this regard, no assessment can be made in the present cases.

5.4 Summary of Observations

The findings are summarized in the following.

1. At least ten percent of the concrete delivered contained a total air content at, or near, the lower permissible design limit and only one concrete delivery with substantially lower air content than permitted was detected.
2. Over thirty percent of the concrete possessed a slump higher than permitted; however, in no case was there evidence of excess bleeding, laitance, segregation or mixture instability.
3. The compressive strengths of mixtures thought to possess undesirable characteristics initially, such as those with high slump or that had water added, were within specifications with two exceptions.
4. Inappropriate addition of water to the mixture in the truck occurred at approximately seven percent of the sites which resulted in slump values higher than specified, but low strength in only one case.
5. Water was added to the surface of the flatwork prior to finishing at approximately six percent of the sites.
6. Concrete was placed on wet and/or soft subgrades at twenty percent of the sites.
7. In general, there was inadequate compaction effort with premature final finishing of the fresh concrete. However, there was evidence of widespread use of curing compounds on the finished flatwork.

6.0 INDUSTRY INITIATIVES FOR IMPROVED CONCRETE QUALITY

Initiatives that have been undertaken by ARMCA in concert with the field testing work include efforts aimed at establishing a higher quality of flatwork as a standard practice in Alberta. In 1987, a program was started consisting of advertising, seminars, homeshows and distribution of information brochures intended to educate both the public and the industry in matters pertaining to concrete quality. The concept has been adopted by the associations in Saskatchewan and Manitoba and is currently being considered in other provinces and in the United States.

6.1 Concrete Quality

The minimum standard established by code for flatwork mixtures is 285 kg/m^3 minimum cement content, 5 to 8% entrained air, 100 mm maximum slump, and 25 MPa compressive strength at 28 days.

A higher minimum standard in regards to minimum cement content (300 kg/m^3), maximum slump (80 mm) and minimum compressive strength (27.5 MPa at 28 days) has been adopted by some suppliers in Alberta and is referred to as Dura-Mix^R. The primary objective is to simplify the ordering of concrete suitable for exterior flatwork - ordering by product name fixes the mix specification. The cost of Duramix concrete is higher than that for the code established minimum standard.

6.2 Education

It is acknowledged that education of both the industry and the public is required to achieve high durability performance expectations. The quality of the material and its placement are of primary importance for reasons already addressed in this paper. Further, the actions of the homeowner regarding continued curing, snow and ice control and loading are all factors contributing to the durability of the installation.

Finishing seminars are held in major centres as are evening workshops in more remote locations in Alberta for the benefit of placers and finishers of concrete. In addition, regular attendance and the provision of education displays at homeshows is practised for the benefit of all interested parties including the public.

6.3 Certification

An important aspect of proper placement involves the employment of competent concrete finishers. The Alberta Ready-Mixed Concrete Association and the Alberta Construction Association actively support the certification of finishers through the Apprenticeship Certification Program of Alberta Career Development and Employment (A.C.D.E.) which would stipulate a minimum level of training.

Although there is currently a qualification trade training program offered at one location in the province, the level of success common to other trade certification programs in terms of enrollment can only be achieved given the provision of more accessible training facilities. The program has been suspended by A.C.D.E. for the 1990/91 season due to low enrollment.

The ARMCA Technical Training and Development Committee has set an objective to provide assistance with the revival of the apprenticeship program in an expanded form. It is believed that if a training program is provided at both Calgary and Edmonton there would be greater industry employee participation. The ARMCA group is currently urging companies that employ finishers to endorse the expanded program and provide at least one employee per year to take part in it. It is believed that all concrete finishers should complete the program.

7.0 TOWARDS THE DEVELOPMENT OF A STRATEGIC PROGRAM

7.1 Program Requirements

In the final analysis there remain three major elements requiring further attention - consumer awareness, trade certification of concrete finishers and future site inspection requirements.

7.1.1 Consumer Awareness

In addition to education by way of publicity of durability issues as discussed previously, the consumer, identified as either the home owner or the builder, can and should require that concrete be placed only by certified finishers. Naturally, the implementation of this strategy is dependent on the availability of suitably certified finishers and is part of the longer term solution.

7.1.2 Trade Certification

The cement and concrete industry is a cornerstone industrial resource in Alberta, and elsewhere. The industry relies on the resources of the scientific community and indeed is an active participant in promoting the advancement of concrete technology. In this way a significant portion of its overall investment is dedicated on an ongoing basis to ensure that quality product is available in the marketplace. This effort should be complemented with placement of concrete by qualified personnel.

At this time the legislation covering the voluntary training of and the experience requirements for personnel involved with the placement and finishing of concrete is being reviewed and a new proposed draft is expected in late 1990. With due regard for the merits of apprenticeship training, it can only be effective on a compulsory basis.

It is questionable that a rigorous apprenticeship program is warranted for individuals involved only with the placement of residential concrete flatwork. However, as evidenced during this program, finishing of this category of concrete requires, initially at least at the on-site supervisory level, certified personnel. This should be established as a compulsory minimum as soon as practicable. Eventually, all finishers should be certified.

A training program for the inexperienced concrete finisher should contain sufficient hands-on components to provide a meaningful connection between theory and practice. This requirement could be relaxed depending on the student's level of experience. For all finishers, the classroom component should consist of introductory concrete technology topics and should include treatment of durability issues in the context of residential flatwork with consideration for local conditions.

Since both the cement and concrete industry and the home buying public would be the benefactors of such a training program, both the industry and the Government of Alberta should take a proactive role in such an endeavour.

7.1.3 Future Site Inspection

The field testing program has provided a snapshot of the performance of the industry and, in general, has provided data feedback to the industry. The program should be continued.

Further developmental work is necessary to examine ongoing site inspection requirements with respect to funding, administration and enforcement of adherence to specifications and standards. This should include the study of the applicability of municipal bylaw and building inspection solutions. Due to the current economics of residential concrete placement, principally due to its seasonal nature, the adoption of private enforcement solutions is not regarded as promising, at least initially. While it is not considered meaningful to provide site inspection results to homeowners due to their low level of knowledge of such issues, there is merit in the bonded use of an imprint stamp by suitably certified finishers.

Site inspection requirements possibly become less necessary as the level of competence of finishers increases, which depends largely on the success of joint industry/government training and certification programs. In this regard, site inspection using the form and procedures developed during the field testing programs could be adopted on an ongoing basis.

8.0 CONCLUSIONS AND RECOMMENDATIONS

The sites visited represent less than four percent of the total number of installations involving this category of concrete in 1989 in the city of Calgary. While the results and observations of the field testing program are an indication of the quality of materials delivered and workmanship performed, the comments made pertain only to visited sites and not necessarily to the industry as a whole. The fact still remains that the industry norm may be somewhat different from what has been observed and consequently reported herein.

The field testing program, with its data feedback features, addressed a number of key components in the overall objective to develop an effective quality assurance program for this category of concrete. It is concluded that although no serious materials problems were discovered, there exists considerable potential for failure, given severe exposure, as a result of a number of workmanship-related issues.

The following conclusions and recommendations flow from this study:

1. The field testing program has proven to be an effective and efficient method of providing producers with feedback data necessary to take corrective action. The program visibility is a constant reminder to finishers and homeowners. It should be continued as an ongoing effort.

2. There is a need to expand the current research to include an indepth laboratory/field study of finishing techniques. This should be focused on issues related to both setting time of the cement and concrete settlement under a variety of realistic ambient conditions.

3. It is recommended that a strong message be delivered to all residential concrete finishers and the home-building industry reinforcing with them the importance of proper workmanship and its effect on product durability.

4. In view of workmanship factors as the likely most significant cause of potential failure, it is recommended that drivers and finishers be provided ongoing education. Again, the efforts of ARMCA in the provision of finishing seminars at N.A.I.T. and S.A.I.T. and evening durability workshops around the province are laudatory and should be continued and expanded where appropriate.

5. Finally, it is recognized that the effectiveness of education will remain less than optimum unless all finishers are required to acquire a minimum standard of education/training. Once again, the effort of ARMCA in the pursuit of an appropriate trade certification program with Alberta Career Development and Employment is both a realistic and desirable goal.

Figure 1. Fresh Concrete Air Content

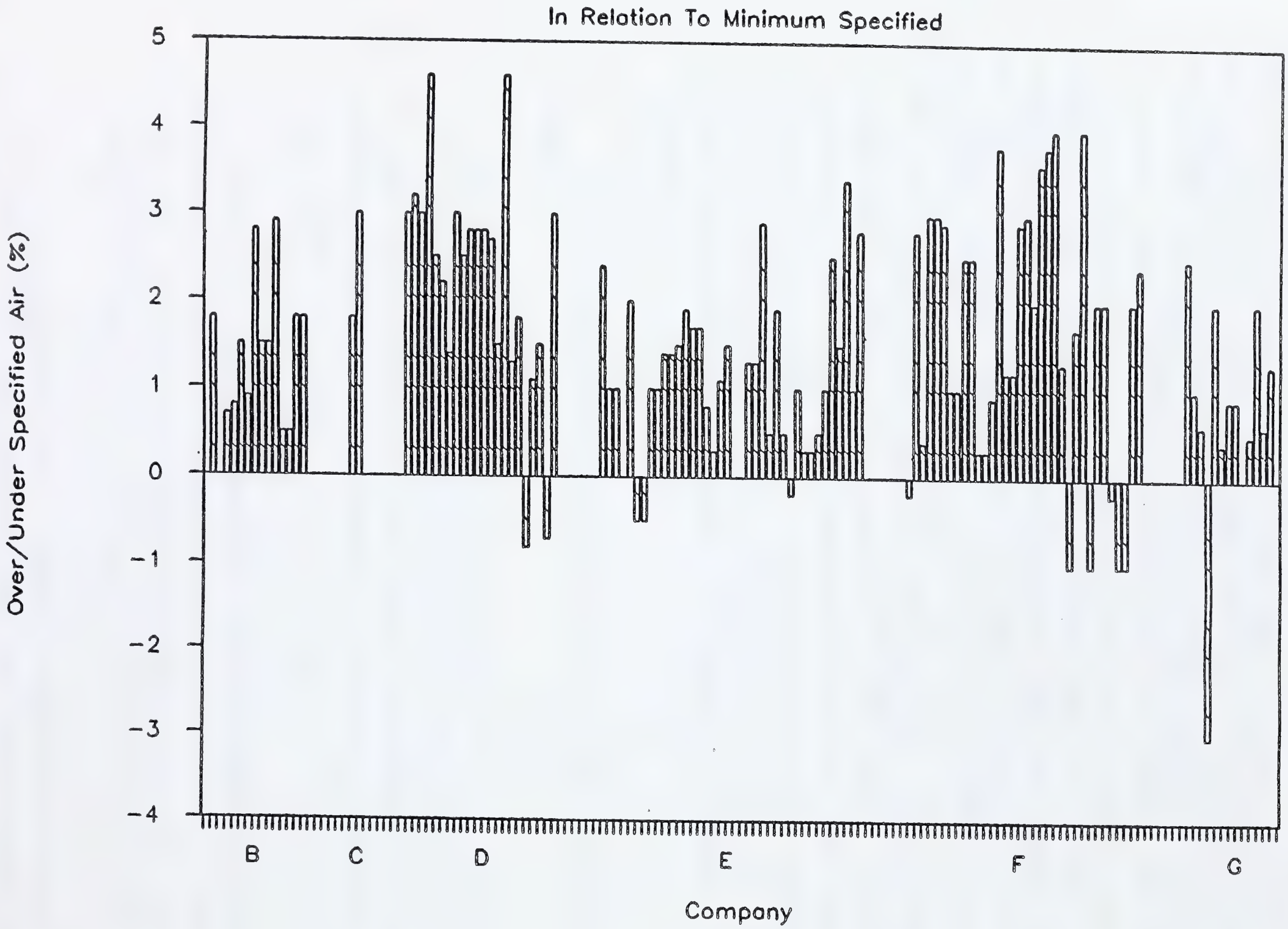


Figure 2. Fresh Concrete Slump

In Relation To Maximum Specified

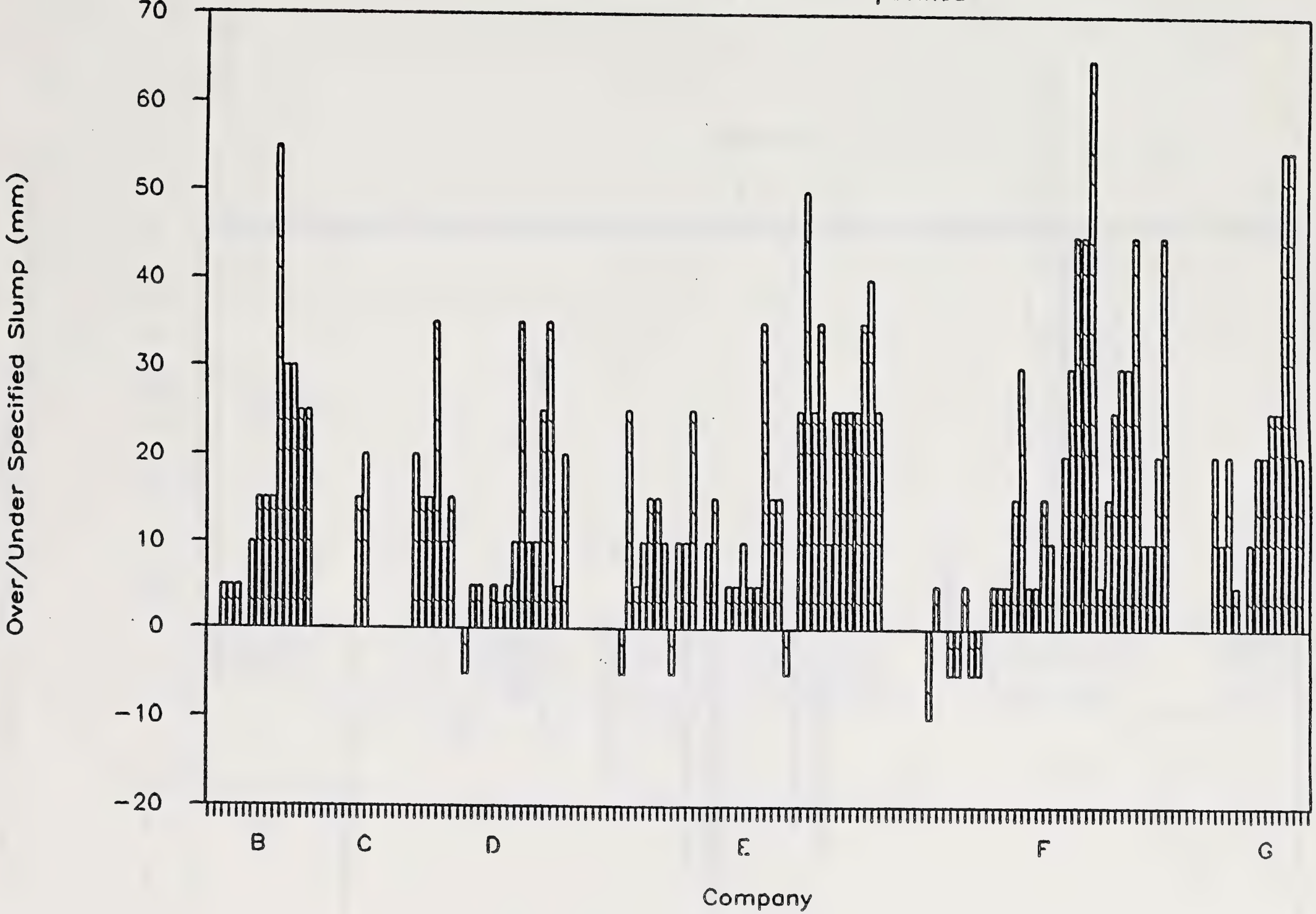


Figure 3. Hardened Concrete Compressive Strength

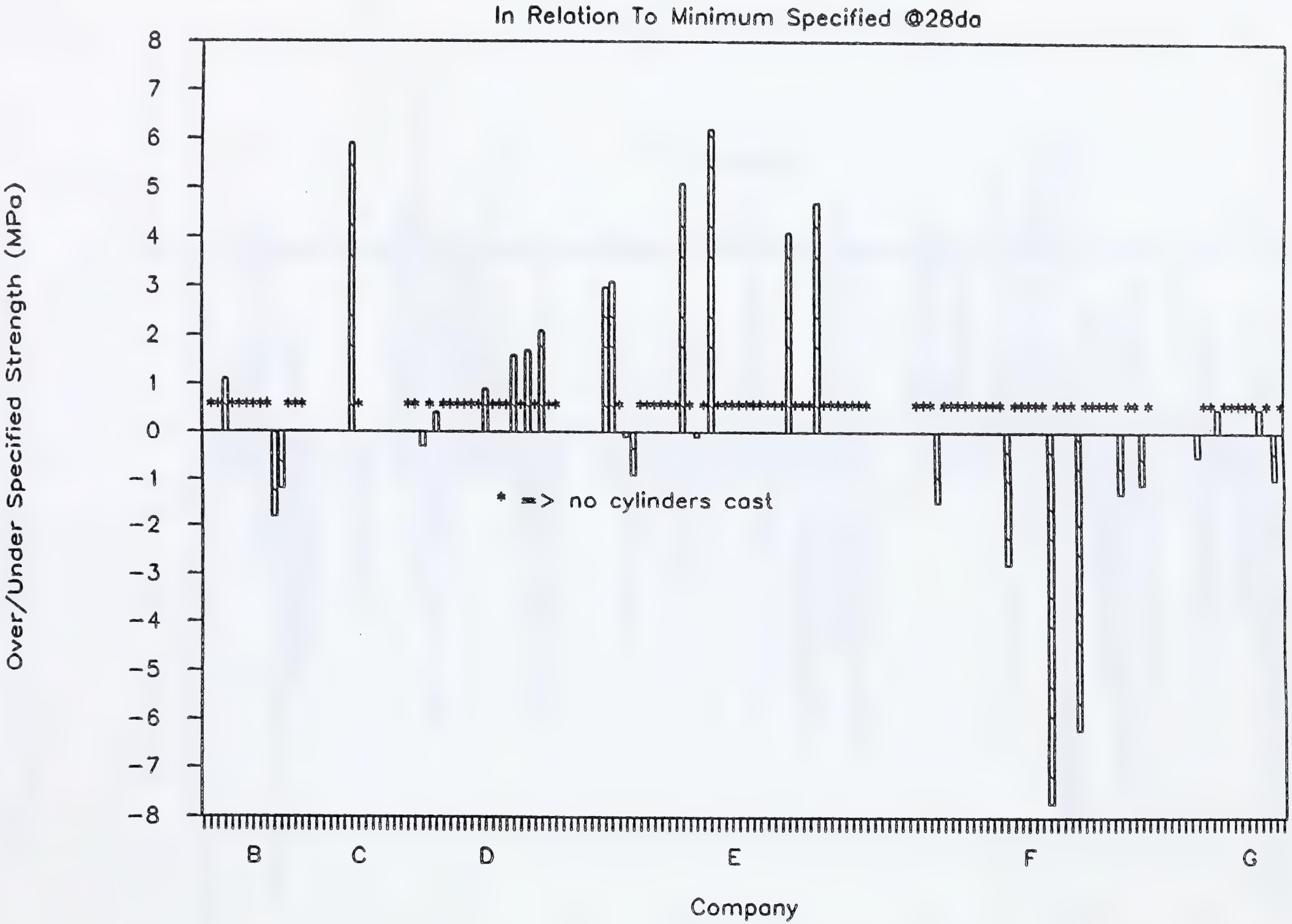
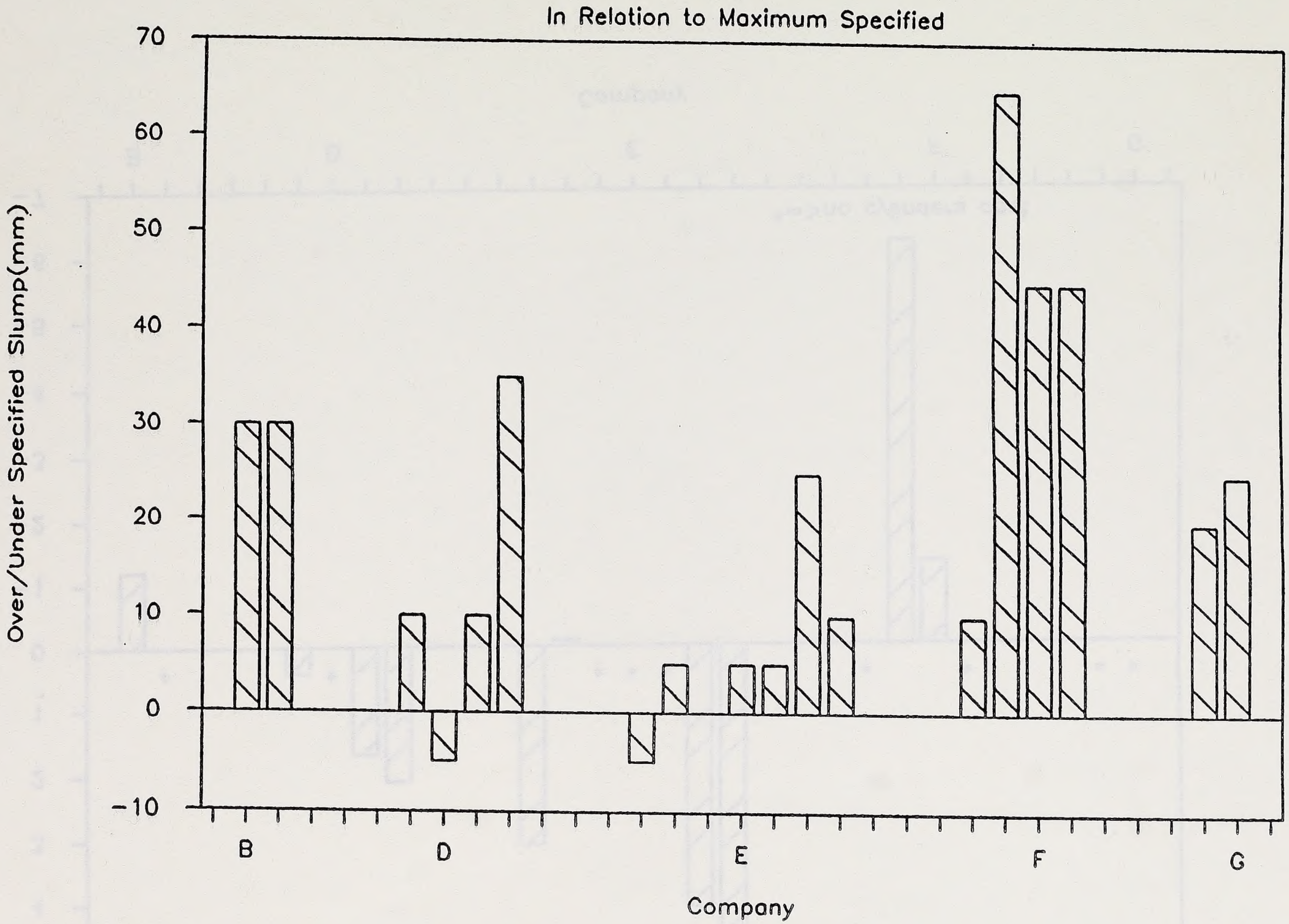
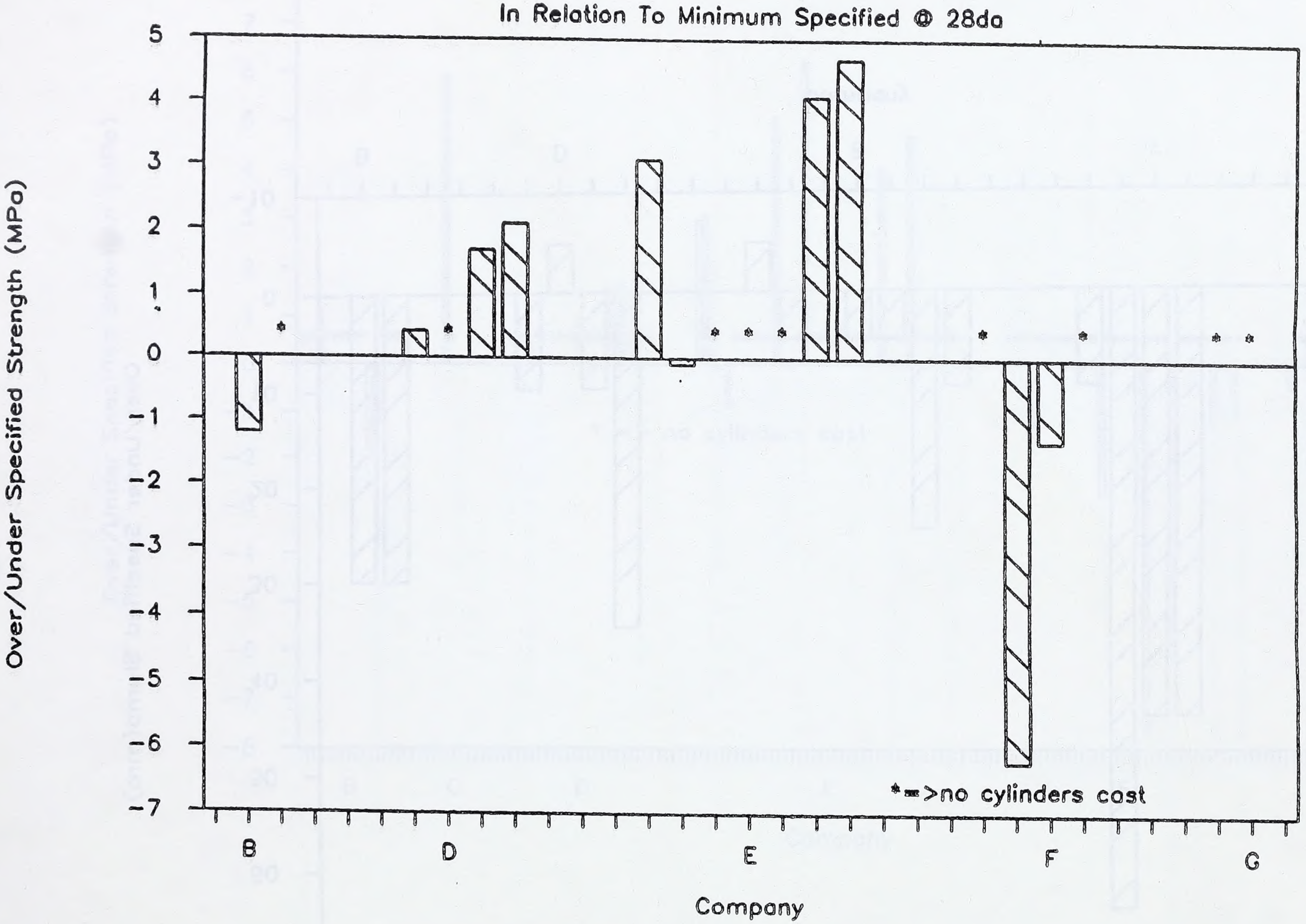


Figure 4. Slump After Water Added At Site



In Relation to Maximum Specified

Figure 5. Strength After Water Added At Site



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